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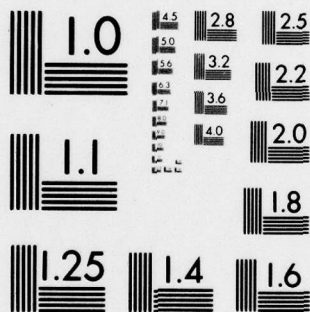
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**STRESS, FATIGUE, AND WORK-REST CYCLES ASSOCIATED
WITH DEEP SUBMERGENCE RESCUE VEHICLE
FLY-AWAY EVOLUTION**

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D. A. HALL, R. E. TOWNSEND, & J. KNIPPA

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STRESS, FATIGUE, AND WORK-REST CYCLES
ASSOCIATED WITH DEEP SUBMERGENCE RESCUE
VEHICLE FLY-AWAY EVOLUTION

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ABSTRACT

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To obtain information on stress, fatigue, and work-rest cycles of both submersible operators and surface support crew members during an actual submarine rescue fly-away mission, six operators and seven surface support personnel (SSP) were monitored during the conduct of a six day trial open-sea submarine rescue evolution using the Deep Submergence Rescue Vehicle (DSRV), Mystic. Operators and crew members lived aboard the mother submarine which carried the DSRV from port to the site of the downed submarine and return. Demographic information, psychological measures, performance measures and environmental data were obtained during pre-deployment, transit-out, at dive site, and transit-in periods. The overall results suggested that a DSRV mission of the present duration and difficulty can be accomplished without exceeding the capabilities of the crew and support personnel. The trend of the changes does, however, suggest that missions of longer duration may require scheduling of regular sleep periods for personnel to maintain performance.
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INTRODUCTION

As deep submergence vehicles (DSVs) develop greater depth capabilities and are given longer duration missions, the physiological and psychological well-being of the operators and surface support personnel (SSP) becomes of increasing importance in insuring successful completion of the mission. Establishment of baseline data on stress and fatigue in submersible operators and SSP is important in determining the safety of present operations and the reserve capability available in the event of unanticipated demands on performance.

During open sea diving operations, significant increases in sleep loss, fatigue, and mood disturbance among both divers and support personnel have been documented.^{9,5} While operations involving deep submersibles differ in many respects from saturation diving situations, a number of the fundamental causes of psychological and physiological stress, and disruption of normal sleep-waking rhythms are still present, and may be potentiated by the greater duration and repetitive nature of submersible operations.

There is presently little data available on the work, sleep disruption, and psychological and physiological stresses placed on submersible operators and SSP.² Data from a number of other situations have clearly demonstrated that disruptions in sleep-wake cycles impair the accuracy and efficiency with which a variety of mental and physical tasks can be performed.¹ Such disruption of the sleep-wake cycles has been documented during even short duration saturation diving operations⁹ and anecdotally reported to occur during sustained DSV operations.

One such DSV is the Deep Submergence Rescue Vehicle (DSRV) (Fig. 1) whose primary mission is to provide a quick reaction capability to rescue personnel from a disabled submarine. The U. S. Navy Deep Submergence Rescue System includes two DSRVs, a Submarine Rescue Unit (in San Diego, California), two ASR-21 class Submarine Rescue Ships, and a number of specifically configured mother submarines.

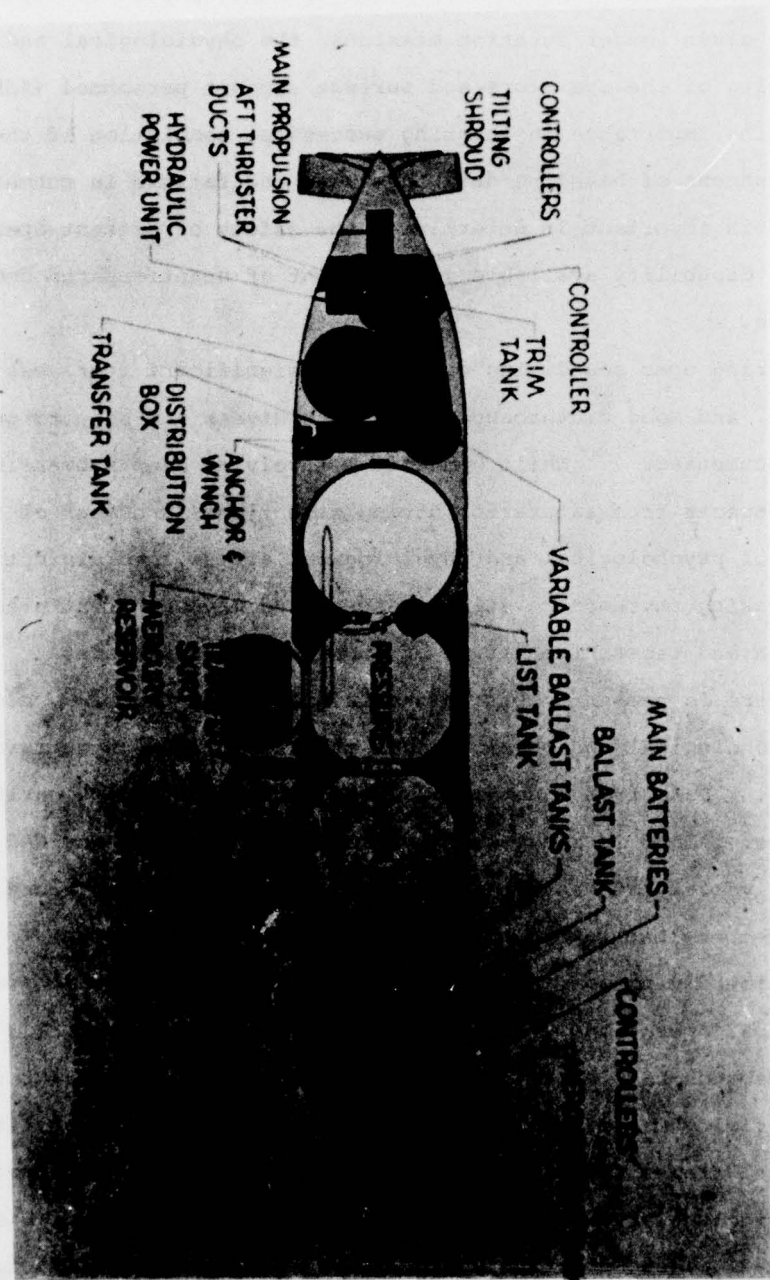


Fig. 1 Deep Submergence Rescue Vehicle Configuration

Briefly, the Rescue System functions as follows: upon receipt of deployment orders, the DSRV is transported from the homeport to the designated support ship, either directly by land on its Land Transport Vehicle or via C-5 or C-141 military aircraft. Upon arrival at the designated port nearest the location of the distressed submarine, the DSRV and its support equipment are loaded aboard a mother submarine, ASR, or ship of opportunity. Upon reaching the rescue site aboard the support ship, the DSRV is launched, piloted to the distressed submarine, and mated to the escape hatch, in as many round trips as necessary to remove all survivors and deliver them to the support ship. When operating with the ASR, personnel exit takes place with the DSRV hoisted aboard. With a mother submarine, the rescuees and the crew transfer into the forward room through the escape hatch in a submerged mating similar to the rescue mating.

The DSRV can carry up to 24 rescuees at one time. Thus, the rescue of the entire crew of a large nuclear submarine could require as many as seven or more trips. Each round trip would require several hours plus an hour or more turnaround time at the support ship for battery charging, life support replenishment, and reballasting. The DSRV can mate with most modern submarines. The exact requirements for compatible mating surfaces have been distributed to interested foreign navies. Mating can be accomplished at angles of up to 45°.

The purpose of the present study was to obtain information on stress, fatigue, and work-rest cycles of both submersible operators and surface support crew members during an actual multi-day submarine rescue fly-away mission. It was expected that the results would suggest possible areas of weakness or limitations which might affect the endurance capability of rescue operations.

METHODS

Six experienced U. S. Navy submersible operators and seven U. S. Navy SSP were studied before and during a 6-day deployment, the purpose of which was to demonstrate the viability of the DSRV-1, Mystic's, rescue capability.

The evolution consisted of 5-day pre-deployment, 2-day transit-out, 2-day on-site and 2-day transit-in data collection periods. The following measures were obtained:

Demographic Information.

At the beginning of the data collection period, each participant was asked to complete a brief questionnaire designed to provide background information on age, education, and experience in submersibles and diving. Included were questions dealing with crew position, number of previous dives, submersible accidents, and diving or submersible-related medical problems.

Psychological Measures.

NHRC Sleep Log: The NHRC Sleep Log was a daily record of subjective evaluation of sleep. Included are self-ratings of difficulty falling asleep, time taken to fall asleep, number of awakenings, need for additional sleep, degree of restedness following sleep, number of hours of work in the previous 24 hours, and the clock time of sleeping and waking during the previous 24 hours. The sleep log was based on a similar instrument developed by Hartman and Cantrell³ and used in previous diving studies.⁸

Stanford Sleepiness Scale (SSS): The SSS was a 7-statement self-rating scale to describe alertness and ability to function, ranging from alert, wide awake, to unable to remain awake.⁴

Profile of Mood States (POMS): The POMS is a 65-item, 5-point adjective rating scale which provides information on the mood or affective states of Tension-Anxiety, Depression-Dejection, Anger-Hostility, Vigor-Activity, Fatigue-Inertia, and Confusion-Bewilderment.⁶

The second part of the study involved a smaller portion of operators and crew members and the following data were collected:

Four-Choice Reaction Time Performance: The Four-Choice Reaction Time Task¹¹ is a modified cassette recorder with four stimulus lights and four corresponding response buttons. The task is to press the button corresponding to the stimulus light that is on. Each response turns off the light that is on and causes another light to come on in a random order. The operator's task

was to push the button corresponding to each light that came on as quickly as possible without making mistakes for a five minute period. Reaction times and errors were recorded on the self-contained cassette tape. Four-choice reaction time performance was obtained during the five operational stages of the mission.

Environmental Data: The internal environment of the submersible was monitored by existing sensors. These data included PO_2 , PCO_2 , temperature, and humidity.

The Fly-Away team departed San Diego for New London, Connecticut, in two groups, 24 hours apart due to adverse weather conditions. The principal investigator was with the second group and therefore some data were not collected from the first group during the first 24 hours of the deployment.

RESULTS

Demographic Information.

Table I shows the demographic data and indicates little intracrew variability except in the area of the number of previous submersible dives logged by crew members. There were no significant medical problems or histories of experience with submersible accidents.

TABLE I
Demographic Data

<u>Variable</u>	<u>Mean</u>	<u>S.D.</u>
Age	32.9	4.96
Education	13.5	1.76
Number of Previous Submersible Dives	32.5	27.50
Years in DSRV	1.6	0.23
Number of Dives in DSRV	25.1	0.35

Psychological Measures.

Sleep Log: Table II shows the means and standard deviations for the Sleep Log variables affected by the different phases of the operation. The

major changes in sleep occurred during the Transit-Out phase, with fragmentation of the sleep-wake cycle, reduced sleep time, decreased feelings of restedness, decreased time to fall asleep, and fewer nocturnal awakenings. There was also an increase in the number of hours worked in each 24 hour period.

TABLE II
Sleep Log

Variable	Pre-deployment		Transit-Out		Dive		Transit-In		p
	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	
Time to fall asleep (Min)	11.8	11.8	8.7	12.2	12.5	9.8	7.0	7.4	ns
Number of times woke up	2.0	2.6	0.5	0.7	1.9	3.0	1.3	1.9	.03
How well rested	1.5	0.6	2.6	1.2	2.1	0.9	1.8	0.9	.001
No. of Hrs worked/24 Hrs.	6.3	3.9	17.4	6.3	12.2	5.6	11.6	3.6	.001
Total sleep duration (Hrs)	7.1	2.9	5.1	4.9	5.7	3.1	5.7	2.3	.002
Inter-sleep interval (Hrs)	17.4	8.4	11.9	11.4	14.3	6.9	17.3	7.2	.02

Stanford Sleepiness Scale (SSS): There were no significant changes in the SSS. However, the trend of changes was consistent with the sleep loss indicated on the Sleep Log.

Profile of Mood States (POMS): Results of the analysis of the POMS data are shown in Table III as the means and standard deviations for each mood variable for each phase of data collection. Analysis of variance indicated a significant ($p < 0.05$) interaction of phase of the operation with mood, indicating that the mood variables were affected in different ways by the different phases of the operation. The Transit-Out phase was clearly the most disruptive of the four, with six of the seven mood variables being most disturbed during this phase.

TABLE III
Profile of Mood States

	Predeployment		Transit-Out		Dive		Transit-In	
	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD	\bar{X}	SD
Depression	2.54	2.40	3.00	4.00	1.32	2.48	0.96	1.71
Vigor	20.71	4.92	14.79	6.30	16.75	5.27	18.25	5.59
Fatigue	3.06	2.54	9.11	4.78	5.82	4.36	3.75	3.36
Anger	2.71	2.86	2.54	2.69	1.57	1.74	3.07	4.72
Tension	5.57	3.30	5.96	3.52	4.14	2.64	3.61	2.64
Confusion	3.20	2.44	4.75	3.36	3.57	2.59	2.86	2.18
Total Mood Disturbance	-3.70	14.25	10.57	20.13	-0.32	15.55	-4.00	16.27

ANOVA - MOOD DATA
DSRV Fly-Away

Source	SS	df	ms	F	p
Total	14,430.648	335			
Subjects	868.073	13			
Periods	94.065	3	31.355	3.384	< .05
Moods	9,601.966	5	1920.393	60.622	< .001
Periods X Moods	615.421	15	41.028	9.631	< .001
Error Periods	361.425	39	9.267		
Error Moods	2,059.09	65	31.678		
Error Periods X Moods	830.608	195	5.260		

Four-Choice Reaction Time: Figure 2 shows the changes in mean reaction time for correct responses and the number of incorrect responses over the course of the operation. Because of non-normality of the distributions,

analysis of variance by ranks¹⁰ was used. Changes in reaction time for correct responses were significant ($X^2_r = 15.36$, $df = 4$, $p < 0.005$), with slowest reaction times occurring during the Baseline and Transit-Out phases. Following one night of recovery sleep, reaction times were markedly faster and remained so during the two dive days.

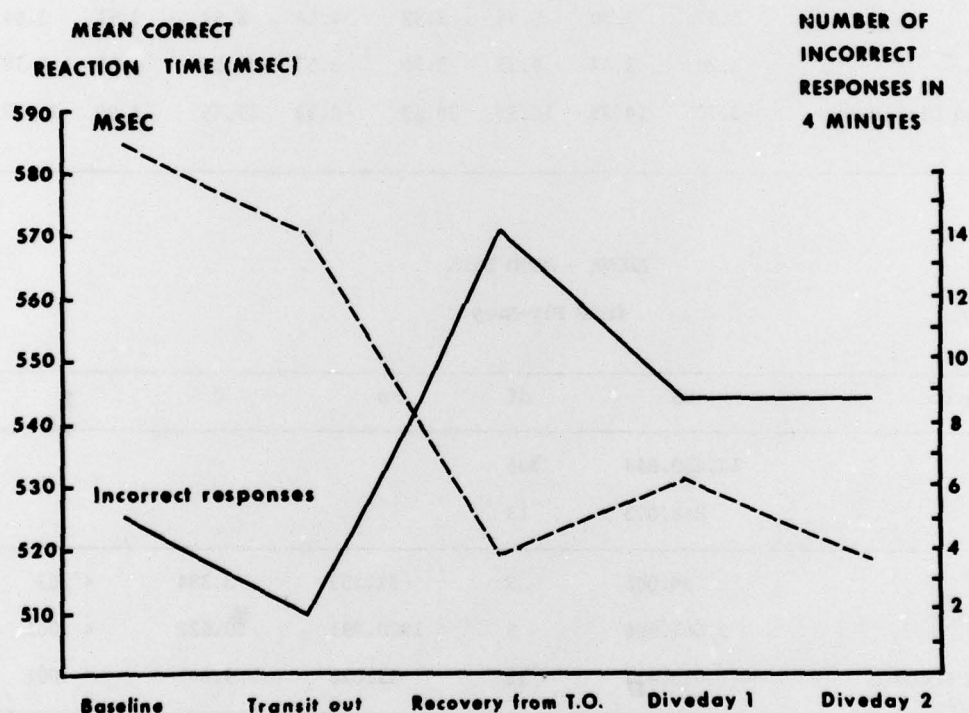


Fig. 2 Changes in mean RT for correct responses and number of incorrect responses on 4-choice RT task

There were also significant changes in number of incorrect responses during the operation ($\chi^2_r = 12.6$, $df = 4$, $p < 0.02$). Fewest errors were made during Baseline and Transit-Out phases; most errors were made following recovery from Transit-Out. Changes in the number of gaps during the operation were not statistically significant.

Environmental Data.

PO₂, PCO₂, temperature and humidity were all within normal limits and did not show changes which would be expected to influence physiological or psychological function.

DISCUSSION

The overall results of the study were in the expected directions and confirmed the moderately disruptive effects on sleep and mood of short duration DSRV missions. The Transit-Out phase proved to be the most disruptive of the four phases, with maximal negative effects on ten of the thirteen measured sleep and mood variables. The increased workload involved in the pre-dive preparation of the DSRV and transit of the DSRV to the dive site resulted in a greatly increased number of hours of work per 24 hour period, which remained moderately elevated throughout the operation. The decrease in the intersleep interval during Transit-Out indicates that the sleep pattern shifted from one sleep period per 24 hours to a more fragmented pattern with an average of 12 hours from sleep onset to the next sleep onset. Inspection of the unaveraged data indicated that this shift from approximately 17 hours to 12 hours intersleep interval represents a decrease in the length of the major sleep period and an increase in the number and duration of naps.

The decline in total sleep duration to 5 to 6 hours per 24 hour period approaches the limit which was found to be the minimum sleep duration which could sustain performance in situations where sleep reduction was gradually and carefully controlled.⁷ The rather abrupt decrease in sleep duration observed during the present evolution would be expected to result in increasing fatigue and consequent impairment of performance had the mission been more demanding or extended beyond the four days of transit-out and dive operations.

Results of the Profile of Mood States were consistent with the pattern of sleep disruption and indicated increased Fatigue, Decreased Vigor and increased Total Mood Disturbance during the Transit-Out phase. Although statistically significant and consistent in terms of direction, the absolute magnitude of the mood changes were generally within normal limits, although the trends suggested that a longer duration mission might result in changes which would exceed normal limits. It should also be noted that there appeared to be a reluctance on the part of some subjects to admit "on paper" to increased mood disturbance, thus, the actual mood changes may have exceeded those reported.

During the mission there was no subjective evidence of performance impairment which would affect the ability of the DSRV crew to successfully complete their task. The Four-Choice Reaction Time Task did show statistically significant changes in both speed of correct reaction time and number of incorrect responses. However, actual magnitude of change in reaction time was small and is not considered to be of any practical significance and, in fact, both reaction time and number of incorrect responses may not be related to limitations in ability. The overall pattern of change suggests that during Baseline and Transit-Out, the subjects tended to maximize correctness of response at the expense of relatively longer reaction times. During recovery from Transit-Out and the dive days this response strategy apparently shifted to one of maximizing speed of reaction time but with a consequent increase in the number of incorrect responses.

If the results of the four-choice task reflect a general trend in performance strategies during a mission, it would be important to emphasize correctness of response, since even during the phases with the slowest reaction times, speed of correct response was still relatively fast and errors were few in number.

The overall results suggest that a DSRV mission of the present duration and difficulty can be accomplished without exceeding the capabilities of the crew and support personnel. The trend of the changes does, however, suggest that scheduling of regular sleep periods for personnel may be necessary to maintain performance during more extended evolutions.

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